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RENEWABLE ENERGY SOURCES

An Update Technology for Integrated Biomass Gasification Combined Cycle Power Plant[1]

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Abstract—A discussion is presented on the technical analysis of a 6.4 MW_e integrated biomass gasification combined cycle (IBGCC) plant. It features three numbers of downdraft biomass gasifier systems with suitable gas clean-up trains, three numbers of internal combustion (IC) producer gas engines for producing 5.85 MW electrical power in open cycle and 550 kW power in a bottoming cycle using waste heat. Comparing with IC gas engine single cycle systems, this technology route increases overall system efficiency of the power plant, which in turn improves plant economics. Estimated generation cost of electricity indicates that mega-watt scale IBGCC power plants can contribute to good economies of scale in India. This paper also highlight's the possibility of activated carbon generation from the char, a byproduct of gasification process, and use of engine's jacket water heat to generate chilled water through VAM for gas conditioning.

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1. INTRODUCTION

Increasingly heavy demands are expected on future power plants in terms of efficiency, environmental concerns, fuel flexibility and power production costs etc. Integrated Biomass Gasification Combined Cycle (IBGCC) is an innovative electric power generation technology that combines modern biomass gasification with gas engine and steam turbine power generation technologies. Fuel gas produced by a gasifier is cooled, cleaned and burned in a gas engine to produce electric power. Heat recovered from the hot exhaust of the gas engine produce steam that powers a steam turbine generator to produce additional electric power.

IBGCC power plants are environmentally acceptable and easily sited [1]. Atmospheric emissions of pollutants such as so_x are very low, since biomass contains less sulfur. Water use is lower than conventional steam based power plant because gas engine unit require little amount of cooling water, an especially important consideration in areas of limited water resources or areas, where water is costly. Due to their improved efficiency, less biomass is used per megawatt-hour of output, causing ibgcc power plants to emit less carbon dioxide (CO_2) to the atmosphere, thereby decreasing global warming concerns. Less biomass use also reduces disposal requirements for ash or char if there is no market for these materials. However, the char and activated carbon, after activation of the char has a potential market.

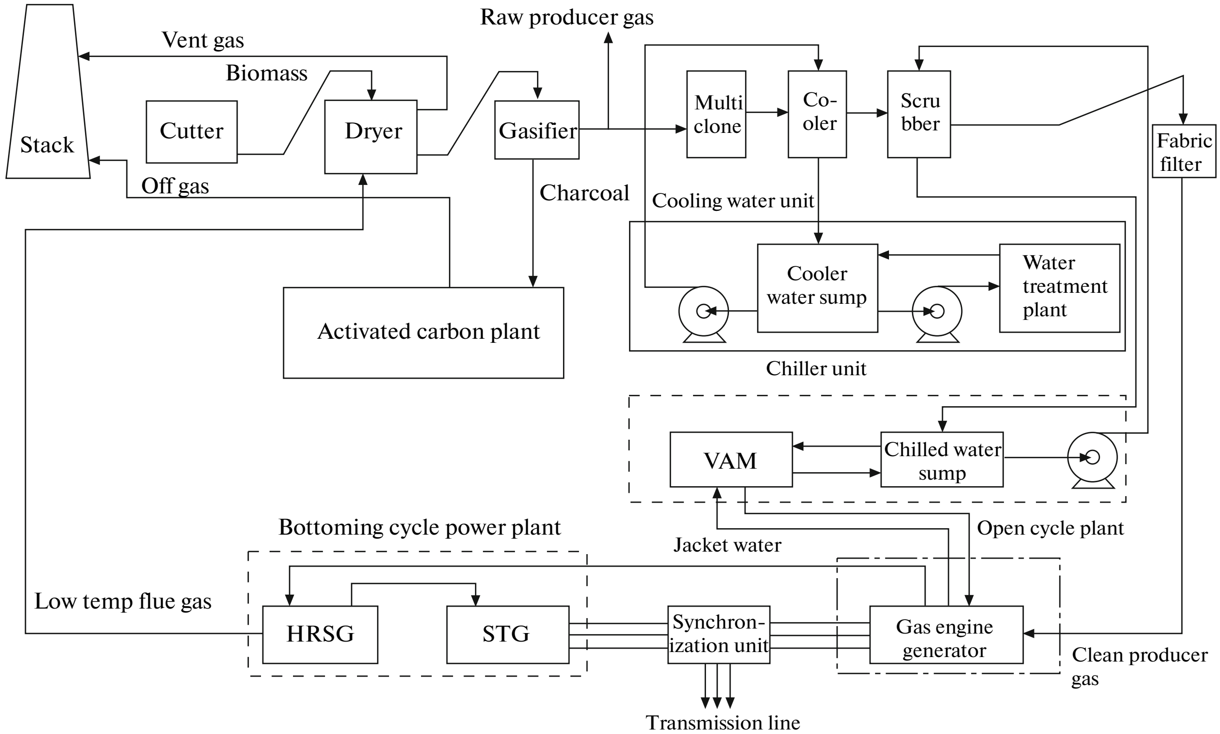
Efficiency improvements are expected to result from design improvements, which increase overall steam and thermal integration, and other technology enhancements such as use of engine's jacket water heat to generate chilled water in a Vapor Absorption Machine (VAM) and use the chilled water for process gas conditioning and use of residual heat from the Heat Recovery Steam Generator (HRSG) for drying of biomass in the dryer. The net electrical conversion efficiency (biomass fuel to electricity) is projected to be approximately 35% for the IBGCC plants, compared to 20–25% for conventional biomass combustion plants [2] of similar capacity.

The potentially significant increase in efficiency makes IBGCC attractive.

2. PLANT DESCRIPTION

The IBGCC power plant described in this paper comprises of gasification plant, which would supply producer gas to reciprocating engines. Power generated from the reciprocating engine generator sets would be evacuated by transformers connected to the local grid. The reciprocating engine's exhaust would be connected to the HRSG and the exhaust from the HRSG would be connected to the biomass dryer. The engine jacket water heat would be effectively utilized to generate chilled water by VAM and the chilled water would be utilized for gas conditioning. The charcoal generated from the biomass gasifier would be used in activated carbon plant to produce activated carbon

[1] The article is published in the original.



Flow diagram of IBGCC power plant.

when wood is used as feedstock fuel. The flow diagram of the plant is shown in Fig. 1.

2.1. Gasification Plant

The gasification plant would consist of three gasification reactors to meet the requirements of three numbers 1950 kW gas engine generators (at PF 0.8). Typical consumption of biomass for power generation would be about 1 ± 0.1 kg/kW h, depending on ash and moisture contents of the biomass. The gasifier would be downdraft type. The gasifier would consist of a vertical tubular reactor with an open top and a conically tapering bottom. The reactor would be provided with a number of radially arranged air nozzles, which provide the restricted combustion zone with air. The lower two thirds of the reactor, where the reactor bed temperature exceeds 600°C, is lined with ceramic material of low thermal conductivity to prevent corrosion by hot gases. The top of the reactor is kept open during the entire operation of the system, to facilitate primary air induction and loading of feedstock. A motorized ash extraction system is provided at the reactor bottom, with a mechanism for intermittent extraction of char. The calorific value of the gas thus generated in the reactor is of the order of 4.5–5.0 MJ/N m^3, with an average composition of CO: 18–20; CH_4: 2–4, H_2: 18–20, CO_2: 12 and rest, N_2.

2.2. Gas Cleanup

Gas cleanup equipment in the IBGCC power plant is relatively smaller in size compared to flue gas cleanup in a steam based power plant of similar capacity. IBGCC plant requires smaller equipment because a much smaller volume of gas is cleaned.

2.2.1. Hot cyclone. The hot, combustible gases generated in the gasifier reactor are drawn below the throat and taken via an insulated duct to a multi-clone where the particulates are stripped off from the gas due to centrifugal action. The gas beyond this goes to cooling and filtering systems.

2.2.2. Cooling and filtering unit. The hot combustible gases leaving the multi-clone are led to a cooler having swirl sprayer arrangement for cooling the gas by direct impingement. This gas cooling reduces the temperature of the gases to near ambient, increases their density, facilitating better mass flow for induction into gas engine. The cooling water, in addition to cooling, also scrubs the gases thus reducing the tar and particulate load. The cooling water is then sent to an off-line chemical cleaning system where it is cleaned by flocculation and then sent to a cooling tower for reducing its temperature after which it is re-cycled in a closed loop. The cooled gas is then led into a chilled water scrubber to reduce the tar further. The chilled water is likewise cleaned by flocculation. A branch from the gas line passes through a valve into a blower and then into a flare burner for emergency flaring. The gas then passes through a set of high efficiency fabric filters to

reduce the residual particulates and then feed into gas engines.

2.3. Auxiliaries

The auxiliaries for this power plant are: i—biomass sizing system (cutter and shredder), ii—biomass drying system (rotary dryer), iii—biomass briquetting (screw press) machine iv—biomass conveying system, v—water treatment plant, vi—cooling tower and vii—char extraction unit.

2.4. Instrumentation

Temperature, pressure, tar and particulate and oxygen contents in the gas are to be measured to monitor the health of the gasifier system.

2.5. Power Island

The power island would consist of three numbers gas engine generators and one number steam turbine generator and electrical systems, associated auxiliary subsystems and also grid synchronizing unit.

2.5.1. Gas engine. The processed gas would be delivered at 15°C to the three gas engine units, where it would burn to produce power. Each engine generator would be rated for 1950 kW output at generator terminals at 0.8 PF. Each of the above synchronous generators would be connected to 415 V switchgear. The voltage would be stepped up to the required voltage for evacuation. The engines would be spark ignited reciprocating type, four-stroke, medium speed suitable for producer gas applications.

The engines and their auxiliary systems would be cooled by water in closed circuit, which in turn would transfer the heat to VAM water circuit through a heat exchanger. Cooling is achieved through heat exchange between closed loop cooling water and atmospheric air in the radiators without physical contact.

2.6. Flue Gas Circuit

The hot exhaust would leave the gas engines and enter a single common HRSG with partitions, which would generate steam at 10.5 kg/cm^2 pressure and 300°C temperature. The exhaust from the HRSG would be supplied to the biomass driers and then vented out to the atmosphere through stack.

2.7. Heat Recovery from Engine Jacket Water

It is possible to recover the energy in the hot water from the jacket water of the three engine sets. The hot water generated would be used in VAM to generate chilled water. The chilled water would then be utilized for the purpose of gas conditioning. The estimated tones of refrigeration (TR) to be produced from the heat energy recovered from the jacket water of each engine set would be about 135 TR. The power consumption for VAM is less when compared to a vapor compression machine.

2.8. Bottoming Cycle Plant

HRSG would recover the heat content of the engine's exhaust gas. The steam generated would then be expanded in condensing type steam turbine driving electric generators. The three engines with the exhaust at about 450°C could generate power output of 500–550 kW.

2.8.1. Heat recovery steam generator. A common single pressure, two pass vertical type HRSG would be adopted for the three engines with partition for flue gases separation.

2.8.2. Steam turbine generator. The steam turbine would be single pressure, single cylinder and straight condensing type with bottom mounted condenser. The steam turbine would be coupled with a generator.

2.9. Water Treatment Plant

The water from the gas cooler and water scrubber would be treated and cleaned to remove the par-ticulate matter and tar content accumulated during the gas conditioning. The system would be complete with settling tanks, pressure sand filter, activated carbon bed, circulation pumps and centrifuge/decanter. The water from the cooler-scrubber system would be pumped to a settling tank where the tar and particulates are flocculated with alum/polyelectrolyte. The water is then passed through sand filter and activated carbon bed.

3. EFFICIENCY

The IBGCC power plant would be designed to have a net heat rate of about 1970 kcal/kW h. IBGCC power plants utilize low rank fuels (even fuel mix). The overall system efficiency is 43% (whereas, bio-mass to electricity efficiency is 32%—higher heating value basis) as compared to 22–25% for conventional combustion plants and IC gas engine based single cycle system of similar capacity. Hence compared to conventional combustion technology, IBGCC can generate about 50% more power from a given source of biomass. Thus the biomass utilization is more effective and less biomass is required for similar generation capacity with respect to combustion technology.

The superior efficiency is a consequence of the system's technology and its design, which includes a high level of system integration. The use of engine jacket water heat for the generation of chilled water and use of exhaust heat from the HRSG for biomass drying as well as power generation make the system more attractive.

Due to improved electrical efficiency, the potential reduction in green house gases is greater than with

Table 1. Expected inputs and outputs at full load, 100% capacity utilization factor

1. Plant capacity, MW_e	6.4 (gross) 5.7 (net)
2. Annual gross electricity production,	46 MU
Inputs	
1. Annual biomass consumption, tones	40000
Outputs	
1. Air emissions, tonnes/yr	
1.1. Particulate matter	21
1.2. Carbon dioxide [4]	2258
2. Aqueous effluents, m^3/day	
2.1 Cooling tower, due to blow down and drift losses	26
3. Solid waste/byproduct, kg/h	
3.1. Saw dust	110–180
3.2. Tar and particulates	11–12
3.3. Charcoal	425

direct combustion technology for each unit of electricity generated.

4. TYPICAL COSTS

Unit size, nature of feedstock, mode of heat recovery chosen, all determines the capital costs for an IBGCC power plant. The capital cost including that for fuel processing system, typically varies between 6.8 and 7.0 Crores/MW as on FY 2009. It excludes the cost for land and land development and preoperative expenses. Expected costs of generation is about 3.8 per kW h considering biomass cost (wood and agro-residues briquettes) of 915/tone.

The capital cost and cost of generation of the IBGCC power plant are relatively higher when compared with electricity generation by conventional way as well as generation using biomass direct combustion. The cost challenges being the production volumes for major components and indigenous supply of some of the components.

5. BYPRODUCT/WASTE HEAT USING

5.1. Waste Heat Using

The plant description given above utilizes heat to generate maximum power. However, an IBGCC power plant could also offer a cold storage facility by using chilled water generated using waste heat fired VAM. It is possible to run about 3000 tones capacity cold storage facility from the 5.85 MW open cycle power plant after fulfilling the requirements for gas conditioning. In rural economies this would be more beneficial for storing farm products.

5.2. Charcoal Using

The charcoal can be used for generation of activated carbon. Activated carbon has a number of uses in the industry. Selling of activated carbon can also reduce the cost of electricity generation to a large extent.

6. ENVIRONMENTAL CONSIDERATIONS

The IBGCC power plant is designed to have a low environmental impact. Because of the plant's inherent high efficiency, in the order of 43%, the plant would use much less natural resources (biomass, and water) than a conventional steam based power plant [3]. Use of water is 30% less than that of conventional steam based power plant of similar capacity and biomass requirements is about 0.87 kg/kW h. Table 1 shows expected inputs and outputs of the IBGCC plant.

The generation point of these byproducts/effluents and possible use are shown in the following Table 2.

Table 2. The generation point of byproducts/effluents and their possible use

Byproduct/Effluent	Generation point	Use
Saw dust	Cutting station	Briquette production
Occluded dirt	Dryer, sieve	Land fill or as a mineral supplement to the nearby agricultural fields
Charcoal (agro-residues)	Gasifier	Sale
Charcoal (wood)		Use for activated carbon production
Wet sludge cake	Centrifuge	Incinerated or sold to road laying contractors
Tar, particulates	Multi-clone	Sale
Blow down water	Cooling tower	Gardening, in the power plant area
Ash	Activated carbon plant	Land fill

7. ECONOMIC AND SOCIAL CONSIDERATIONS

There are many social benefits of using biomass for energy production, viz. the creation of a market for biomass fuels, local employment opportunities for entrepreneurs and development of skills, rural stability on an environmentally sound basis, local control of reserves, and promotion of an appropriate economic infrastructure.

8. CONCLUSIONS

The efficiencies of the IBGCC power plants explained in this report is in the order of 43–45% as compared to 22–25% for conventional combustion plants and IC gas engine based single cycle system of similar capacity. This gives an advantage in terms of fuel consumption.

Conventionally, single fuel is being used in IBGCC power plants. A mixture of biomass fuels (wood and agro-residues) in IBGCC power plant can get the benefits of seasonal fuel availability and cost. The chilled water generated from the VAM can also be utilized for cold storage facilities, which is an additional advantage for the rural areas, in particular. Further, charcoal, a byproduct of gasification process, is a marketable product and can give more value added product, i.e., activated carbon after activation when wood is used as fuel.

It is believed that in the near future, IBGCC power plant would promote rural development in large scale and would be eco-friendly alternatives.

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